Vincent G. Duffy (Ed.)

Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management

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14th International Conference, DHM 2023
Held as Part of the 25th HCI International Conference, HCII 2023
Copenhagen, Denmark, July 23–28, 2023
Proceedings, Part I

Part I

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Vincent G. Duffy
Editor

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Foreword

Human-computer interaction (HCI) is acquiring an ever-increasing scientific and industrial importance, as well as having more impact on people's everyday lives, as an ever-growing number of human activities are progressively moving from the physical to the digital world. This process, which has been ongoing for some time now, was further accelerated during the acute period of the COVID-19 pandemic. The HCI International (HCII) conference series, held annually, aims to respond to the compelling need to advance the exchange of knowledge and research and development efforts on the human aspects of design and use of computing systems.

The 25th International Conference on Human-Computer Interaction, HCI International 2023 (HCII 2023), was held in the emerging post-pandemic era as a 'hybrid' event at the AC Bella Sky Hotel and Bella Center, Copenhagen, Denmark, during July 23–28, 2023. It incorporated the 21 thematic areas and affiliated conferences listed below.

A total of 7472 individuals from academia, research institutes, industry, and government agencies from 85 countries submitted contributions, and 1578 papers and 396 posters were included in the volumes of the proceedings that were published just before the start of the conference, these are listed below. The contributions thoroughly cover the entire field of human-computer interaction, addressing major advances in knowledge and effective use of computers in a variety of application areas. These papers provide academics, researchers, engineers, scientists, practitioners and students with state-of-the-art information on the most recent advances in HCI.

The HCI International (HCII) conference also offers the option of presenting 'Late Breaking Work', and this applies both for papers and posters, with corresponding volumes of proceedings that will be published after the conference. Full papers will be included in the 'HCII 2023 - Late Breaking Work - Papers' volumes of the proceedings to be published in the Springer LNCS series, while 'Poster Extended Abstracts' will be included as short research papers in the 'HCII 2023 - Late Breaking Work - Posters' volumes to be published in the Springer CCIS series.

I would like to thank the Program Board Chairs and the members of the Program Boards of all thematic areas and affiliated conferences for their contribution towards the high scientific quality and overall success of the HCI International 2023 conference. Their manifold support in terms of paper reviewing (single-blind review process, with a minimum of two reviews per submission), session organization and their willingness to act as goodwill ambassadors for the conference is most highly appreciated.

This conference would not have been possible without the continuous and unwavering support and advice of Gavriel Salvendy, founder, General Chair Emeritus, and Scientific Advisor. For his outstanding efforts, I would like to express my sincere appreciation to Abbas Moallem, Communications Chair and Editor of HCI International News.

July 2023 Constantine Stephanidis

HCI International 2023 Thematic Areas and Affiliated Conferences

Thematic Areas

- HCI: Human-Computer Interaction
- HIMI: Human Interface and the Management of Information

Affiliated Conferences

- EPCE: 20th International Conference on Engineering Psychology and Cognitive Ergonomics
- AC: 17th International Conference on Augmented Cognition
- UAHCI: 17th International Conference on Universal Access in Human-Computer Interaction
- CCD: 15th International Conference on Cross-Cultural Design
- SCSM: 15th International Conference on Social Computing and Social Media
- VAMR: 15th International Conference on Virtual, Augmented and Mixed Reality
- DHM: 14th International Conference on Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management
- DUXU: 12th International Conference on Design, User Experience and Usability
- C&C: 11th International Conference on Culture and Computing
- DAPI: 11th International Conference on Distributed, Ambient and Pervasive Interactions
- HCIBGO: 10th International Conference on HCI in Business, Government and Organizations
- LCT: 10th International Conference on Learning and Collaboration Technologies
- ITAP: 9th International Conference on Human Aspects of IT for the Aged Population
- AIS: 5th International Conference on Adaptive Instructional Systems
- HCI-CPT: 5th International Conference on HCI for Cybersecurity, Privacy and Trust
- HCI-Games: 5th International Conference on HCI in Games
- MobiTAS: 5th International Conference on HCI in Mobility, Transport and Automotive Systems
- AI-HCI: 4th International Conference on Artificial Intelligence in HCI
- MOBILE: 4th International Conference on Design, Operation and Evaluation of Mobile Communications

List of Conference Proceedings Volumes Appearing Before the Conference

1. LNCS 14011, Human-Computer Interaction: Part I, edited by Masaaki Kurosu and Ayako Hashizume
2. LNCS 14012, Human-Computer Interaction: Part II, edited by Masaaki Kurosu and Ayako Hashizume
3. LNCS 14013, Human-Computer Interaction: Part III, edited by Masaaki Kurosu and Ayako Hashizume
4. LNCS 14014, Human-Computer Interaction: Part IV, edited by Masaaki Kurosu and Ayako Hashizume
5. LNCS 14015, Human Interface and the Management of Information: Part I, edited by Hirohiko Mori and Yumi Asahi
6. LNCS 14016, Human Interface and the Management of Information: Part II, edited by Hirohiko Mori and Yumi Asahi
7. LNAI 14017, Engineering Psychology and Cognitive Ergonomics: Part I, edited by Don Harris and Wen-Chin Li
8. LNAI 14018, Engineering Psychology and Cognitive Ergonomics: Part II, edited by Don Harris and Wen-Chin Li
9. LNAI 14019, Augmented Cognition, edited by Dylan D. Schmorrow and Cali M. Fidopiastis
10. LNCS 14020, Universal Access in Human-Computer Interaction: Part I, edited by Margherita Antona and Constantine Stephanidis
11. LNCS 14021, Universal Access in Human-Computer Interaction: Part II, edited by Margherita Antona and Constantine Stephanidis
12. LNCS 14022, Cross-Cultural Design: Part I, edited by Pei-Luen Patrick Rau
13. LNCS 14023, Cross-Cultural Design: Part II, edited by Pei-Luen Patrick Rau
14. LNCS 14024, Cross-Cultural Design: Part III, edited by Pei-Luen Patrick Rau
15. LNCS 14025, Social Computing and Social Media: Part I, edited by Adela Coman and Simona Vasilache
16. LNCS 14026, Social Computing and Social Media: Part II, edited by Adela Coman and Simona Vasilache
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18. LNCS 14028, Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management: Part I, edited by Vincent G. Duffy
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28. LNCS 14038, HCI in Business, Government and Organizations: Part I, edited by Fiona Fui-Hoon Nah and Keng Siau
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39. LNCS 14049, HCI in Mobility, Transport and Automotive Systems: Part II, edited by Heidi Krömker
40. LNAI 14050, Artificial Intelligence in HCI: Part I, edited by Helmut Degen and Stavroula Ntoa
41. LNAI 14051, Artificial Intelligence in HCI: Part II, edited by Helmut Degen and Stavroula Ntoa
42. LNCS 14052, Design, Operation and Evaluation of Mobile Communications, edited by Gavriel Salvendy and June Wei
43. CCIS 1832, HCI International 2023 Posters - Part I, edited by Constantine Stephanidis, Margherita Antona, Stavroula Ntoa and Gavriel Salvendy
44. CCIS 1833, HCI International 2023 Posters - Part II, edited by Constantine Stephanidis, Margherita Antona, Stavroula Ntoa and Gavriel Salvendy
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47. CCIS 1836, HCI International 2023 Posters - Part V, edited by Constantine Stephanidis, Margherita Antona, Stavroula Ntoa and Gavriel Salvendy

https://2023.hci.international/proceedings

Preface

Software representations of humans, including aspects of anthropometry, biometrics, motion capture and prediction, as well as cognition modeling, are known as Digital Human Models (DHM), and are widely used in a variety of complex application domains where it is important to foresee and simulate human behavior, performance, safety, health and comfort. Automation depicting human emotion, social interaction and functional capabilities can also be modeled to support and assist in predicting human response in real-world settings. Such domains include medical and nursing applications, work, education and learning, ergonomics and design, as well as safety and risk management.

The 14th Digital Human Modeling & Applications in Health, Safety, Ergonomics & Risk Management (DHM) Conference, an affiliated conference of the HCI International Conference 2023, encouraged papers from academics, researchers, industry and professionals, on a broad range of theoretical and applied issues related to Digital Human Modeling and its applications.

The research papers contributed to this year's volumes span across different fields that fall within the scope of the DHM Conference. The study of DHM issues in various application domains has yielded works emphasizing human factors and ergonomics based on human models, novel approaches in healthcare, and the application of Artificial Intelligence in medicine. Applications of interest are shown across many industries. Job design and productivity, robotics and intelligent systems are among the human-technology modeling and results reporting efforts this year.

Two volumes of the HCII 2023 proceedings are dedicated to this year's edition of the DHM Conference. The first volume focuses on topics related to human factors and ergonomics, job design and human productivity, as well as interaction with robots and exoskeletons. The second volume focuses on topics related to digital health, IoT and AI in medicine and healthcare, as well as modeling complex human behavior and phenomena.

Papers of these volumes are included for publication after a minimum of two single–blind reviews from the members of the DHM Program Board or, in some cases, from members of the Program Boards of other affiliated conferences. I would like to thank all of them for their invaluable contribution, support and efforts.

July 2023 Vincent G. Duffy

14th International Conference on Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management (DHM 2023)

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http://www.hci.international/board-members-2023.php

HCI International 2024 Conference

The 26th International Conference on Human-Computer Interaction, HCI International 2024, will be held jointly with the affiliated conferences at the Washington Hilton Hotel, Washington, DC, USA, June 29 – July 4, 2024. It will cover a broad spectrum of themes related to Human-Computer Interaction, including theoretical issues, methods, tools, processes, and case studies in HCI design, as well as novel interaction techniques, interfaces, and applications. The proceedings will be published by Springer. More information will be made available on the conference website: http://2024.hci.international/.

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https://2024.hci.international/

Contents – Part I

Human Factors and Ergonomics

Contents – Part II

Digital Health

Modeling Complex Human Behavior and Phenomena

Design and Development of a Novel Wearable System for Assessing the Biomechanical and Psychological Risk of the Healthcare Worker

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Abstract. The state of emergency caused by Covid19 increased the risk of biomechanical and psychological problems among healthcare workers and assumed the need to implement a strategy to prevent these. Adopting tools for monitoring parameters related to the previously mentioned risks can be a valid solution to avoid or reduce work-related physical disorders and stress level. The present work describes the design of a multiparameter system for the hospital environment aimed to monitor the musculoskeletal effort and estimate the stress level required to the healthcare workers. The main challenge was to design a wearable system that does not obstacle or disturb the healthcare worker in his/her work activities. The final set-up is the result of a structured co-design in which doctors, nurses and therapists were involved in a focus group, in order to identify the user requirements considering the needs of each profession. The focus group also served to analyze the activities performed by each category of operators selected (nurse, physical therapist and doctors). An emerging key point was that the final device has to adapt to the healthcare operators' work routine without changing it or adding other tasks. In conclusion, the focus group allowed to collect user requirements to design a multicomponent wearable to monitor physical and mental wellbeing in healthcare workers.

Keywords: Healthcare workers · mental wellbeing · physical strain

1 Introduction

The prevention of both biomechanical and psychological risk and the health of the healthcare workers are an essential and priority element also in light of the episodes of burnout and overload that occurred during the pandemic emergency [1]. Health professionals are indeed more likely to experience mental health problems than the general population; in particular, pediatric nurses, physicians and physiotherapists show burnout, anxiety

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and moderate/severe depression as common mental conditions [2, 3]. The COVID-19 pandemic has exacerbated this trend, with 22% of healthcare workers experiencing moderate depression, anxiety, and post-traumatic stress disorder during its peak [4]. Extensive evidence suggests that the healthcare quality and safety strongly depend on workers wellbeing [5]. Tackling mental health problems of the working-age population is crucial because of their negative impact on individuals, families and societies [6].

For what concerns musculoskeletal disorders, they are frequent health disorders and with a great potential for production losses in healthcare professionals [7]. Nurses and physical therapists are the professionals most afflicted by these health issues due to the frequent physical contact with patients [8, 9]. These practices are indeed physically demanding, involving repetitive tasks, high force manual techniques for treating patients, techniques that exert direct pressure on certain joints during the treatment, awkward positioning of joints during certain maneuvers and prolonged constrained postures [9].

In this context, it is mandatory to prepare appropriate tools for assessing and monitoring the health of healthcare workers, even in their various functions.

For the biomechanical factors, the MAPO index has been proposed as a useful tool to assess the risk of work-related musculoskeletal disorders [10], but few applications are shown in the literature findings. About stress and psychological effort, the basic noninvasive techniques for monitoring these conditions are based on Heart Rate Variability analysis (HRV) [11] or Electrodermal activity, with several limitations due to the difficult data processing and calibration of the signals with respect to emotional state detection. Recently some methodologies using wearable systems (wristbands, smartwatches or armbands) and artificial intelligence techniques showed promising results [12]. No integrated approaches are presented.

On these premises, we have identified the need of designing a wearable system that could provide a set of quantitative measurements of different aspects of workplace ergonomics for the main involved clinical operators: medical doctors, nurses and physical therapists. The system requirements were defined by means of a codesign session conducted with a Focus Group (FG).

FG, compared to other qualitative group interview techniques, allow to collect, within the group dynamics, in-depth and enriched opinions that often remain unexplored using other data collection methods, such as individual interviews [13]. In this facilitating environment, the people recruited are encouraged to discuss different experiences and points of view to gather not only "what you think" or "what you feel", but also the underlying reasons for that behavior/thought. Participants are encouraged to talk to each other, asking questions, exchanging anecdotes and generating comments on other people's points of view and experiences; this facilitates the elaboration of ideas [14, 15]. The purpose of a FG is to investigate the motivation that influences feelings, attitudes and behaviors on a given topic; its peculiarity consists in generating in a short time a large amount of data based on the synergy of group interaction [16]. The FG methodology, formulated by Merton et al. in 1946 [17], was originally applied in the advertising and marketing field, but in recent years it has also become very popular in the healthcare field [18, 19], using group discussion to generate and collect data on a specific topic.

This paper aims at describing the co-design of a multiparameter monitoring system for the hospital environment able to monitor in real-time the time needed by each patient

for her/his assistance/care, the musculoskeletal and physiological effort of the clinical operators, and the estimation of the stress level/mental effort of the health professional.

2 Materials and Methods

Participatory design was the methodology adopted for the system design in a codesign session to define the system requirements. In fact, in particular in the clinical setting where the acceptance of innovations by operators is crucial for their deployment into the clinical practice, co-design results to be a win-win model and an appropriate development strategy.

2.1 Study Setting

The authors conducted the study at IRCCS E. Medea, that is the research section of the Association "La Nostra Famiglia", a no-profit organization of social utility whose purpose is to promote and safeguard health care, education and services for people with special needs. The Medea Institute, Placed in Bosisio Parini (Lecco, Italy), Creates synergies between scientific research and clinical activity through innovative rehabilitation interventions for people with disabilities, especially in the developmental age.

The extensive experience in the rehabilitation of pediatric patients takes advantage of a close cooperation among clinicians, physiotherapists, engineers and psychologists, bridging the gap between a human centered vision and technical applications. At Medea, which is the main rehabilitation center of Association La Nostra Famiglia, there are 46 clinicians, 24 physical therapists, 55 nurses, divided into two clinical areas: the neuro-rehabilitation Unit and Psychopathology Unit.

2.2 Participants and Recruitment

The recruitment was done at the neuro-rehabilitation Unit of the Scientific Institute IRCCS E. Medea on a voluntary basis. physiatrists, nurses and physical therapists were enrolled in the study.

2.3 Data Collection and Analysis

A data collection protocol was prepared through a consultative process among three researchers. The protocol was set-up as a structured presentation (Fig. 1) and after showing a short introduction about the project and the goals, it presented the main factors, elements, component of the system: at the end of each phase the suitable tools (free interviews, think aloud, charts with body map - for the design of sensors placement, device positioning and to identify existing discomfort issues in the current situation - questionnaire with Likert scale scoring) were administered to the participants for data collection.

The protocol focused on the following specific themes:

– The expected functions and features of the wearable device, both from a design point of view, such as sizes, comfort, and aesthetics, and from a more technical one

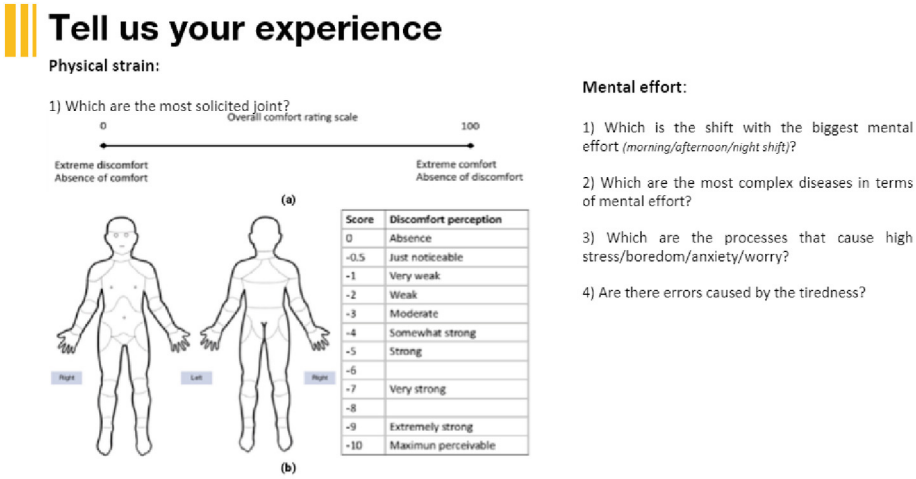

Fig. 1. Example from the presentation shared during the focus group for the mental effort recognition.

concerning the positioning of the sensors for monitoring various parameters such as heart rate, respiratory rate, and motion detection;
- A focus on technologies useful for the collection and monitoring of data about the interaction between healthcare workers and patients, like Radio Frequency Identification (RFID) or Beacon systems;
- An indirect task analysis for each professional role involved regarding the discomfort and physical and psychological stress due to the environment, the type of work, and the procedures performed.

The FG was conducted by four researchers, one senior researcher in Design and Technology, one senior researcher in technological innovations in rehabilitation, mental health and human factors and two junior researchers with an expertise in Design.

The FG was videorecorded. Subsequently, the salient contents of the discussion were extracted according to a classical qualitative methodology of thematic analysis. Three researchers independently listened to the recordings in order to note the main themes verbalized by the focus group participants. Subsequently, the themes were discussed collectively in order to identify the qualitative dimensions capable of summarizing the themes that emerged.

At the end of the FG, each participant was asked to identify a general discomfort/fatigue rating and, on a body map, the location and intensity (on a scale from 0 to –10) of physical strain. Due to the small sample size, these data were analyzed only qualitatively.

3 Results

3.1 Participants

In the first FG, we enrolled 4 participants, 1 physiatrist, 1 nurse and 2 physical therapists. Table 1 shows demographic characteristics of the participants.

Table 1. Demographic data of the participant

Subject	Job title	Gender	Age
S1	Clinician	F	60
S2	Nurse	F	47
S3	Physical Therapist	M	37
S4	Physical Therapist	M	40

3.2 End Users' Point of View

The first outcomes of the FG consisted of the identification of three main topics that the design of such a system should consider: (1) work organization, (2) caregiver-patients interaction, and (3) caregiver-parent interaction. Figure 2 shows a map of the topic and sub-topics that emerged during the FG. Table 2 presents also some quotes related to discussed topics thanks to the think aloud process.

Work Organization. The first topic that the personnel highlighted was organization, considering several aspects: environment, time, and people. The discussion revealed that today spaces and the environment are affecting working conditions. The working environment and the climatic conditions inside cause stress. From the focus group, it emerged that bad conditions such as excessive heat or cold, and lack of natural light can affect the stress of the healthcare worker. By spaces we mean all those areas used to carry out the various medical procedures and, from the focus group, it emerged that they contribute to the discomfort of the medical staff. One of the spaces that create the most cognitive stress is the double room. Nurses complain of this type of organization because it is necessary to frequently transfer one of the two patients during routine procedures or, simply, when one of the two is sick. Other Causes of Cognitive Stress Are shared spaces during physical therapy which can lead to patient distraction and make the physiotherapy session difficult. About this factor a request for a system able to monitor environmental conditions or stress related to these conditions, or a garment with thermoregulation properties should be well considered.

Another issue that emerged during FG was the distribution of nurses during the different shifts (morning, afternoon, and evening) in relation to the number of patients they have to manage. This is another cause of both cognitive and physical stress.

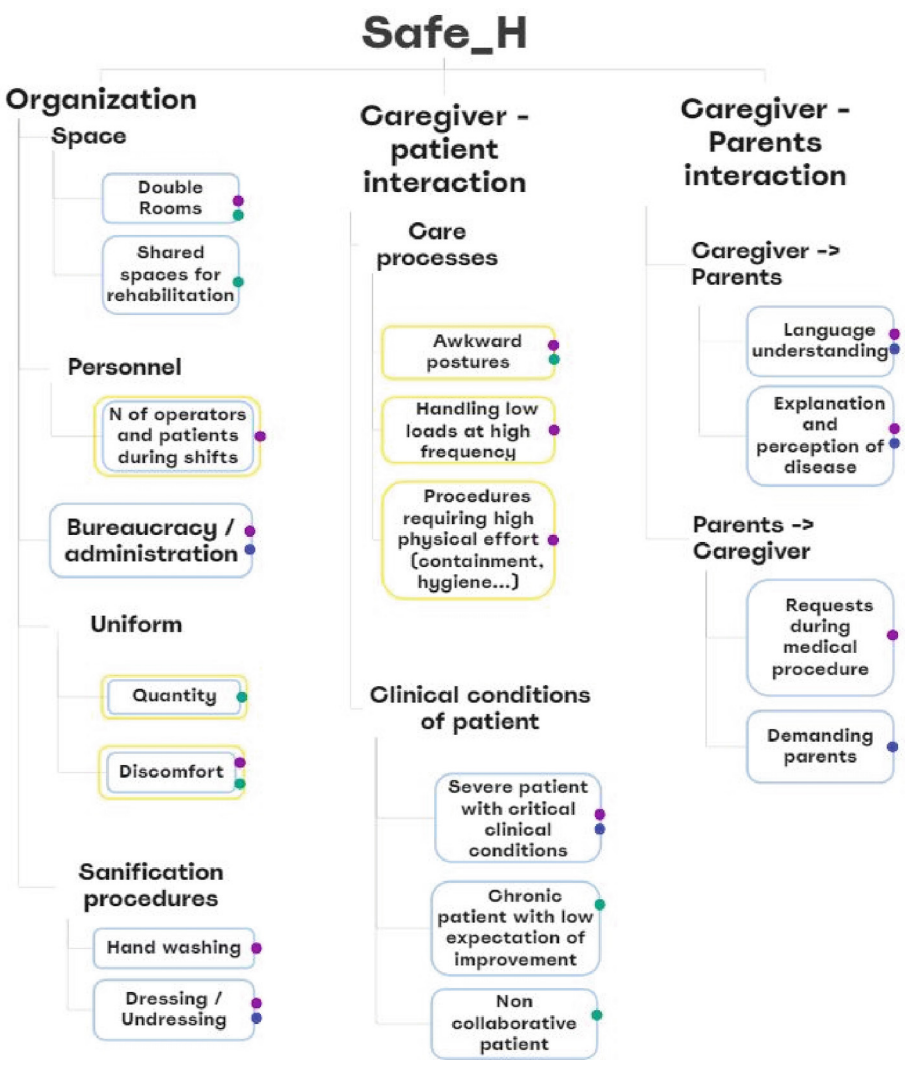

Fig. 2. Map of topics and sub-topics that emerged during the FG. Yellow boxes represent physical stress while blue boxes represent cognitive stress. The colors of the dots represent the caregiver category: purple = nurse, green = physical therapists, and blue = doctor.

Caregivers also discussed about bureaucracy and administration, that was defined as a boring task that takes up a lot of time. Due to this particular theme, caregivers concluded in the FG that they not to want a very demanding additional device.

Another aspect that affects physical and cognitive stress is related to the uniforms. During the focus group, it emerged that while Personal Protective Equipment (PPE) is provided to both nurses and physical therapists, the latter are not given uniforms. Another element of discomfort is the fabric and the shape of the uniform, both of the previously mentioned users find the uniform uncomfortable, some due to lack of pockets and some

Table 2. Identified themes and sub-theme after FG discussion

Themes	Sub-themes	Aspects	Quotes
Organization	Spaces	Double rooms	Intolerance has increased, also towards double rooms. It was already present before, now it has increased exponentially
		Shared spaces for rehabilitation	There are peaks of crowding. From 10.30 am to 2.00 pm, it may be difficult finding a room where to do the rehabilitation activity
	Personnel	Number of operators and patients during shifts	The night for some is considered a quiet moment, for others, instead, a source of stress because they are alone with 28 patients
	Bureaucracy / administration		The stress associated with bureaucracy. Covid has accentuated this aspect. Minutes lost recording
	Uniform	Quantity	Not provided
		Discomfort	The uniforms were not elastic, there were no pockets in the scrub trousers but only in the scrub top
	Sanification procedures	Hand washing	Matter of rolling up your sleeves
		Dressing / Undressing	We wear single use coat to be changed for each patient, over our uniform
Caregiver-patient interaction	Care processes	Awkward postures	When a medication lasts 45 min, in the end, even the body has been affected, perhaps even just for the position held

(*continued*)

Table 2. (*continued*)

Themes	Sub-themes	Aspects	Quotes
		Handling low loads at high frequency	In the pediatric sector, physical effort in moving patients is not very relevant because they are lightweight
		Procedures requiring high physical effort	Physical restraint: I have several colleagues who at the end of the blood sampling say that even their shoulders hurt
	Critical conditions of patient	Severe patient with critical clinical conditions	There is cognitive stress in clinical treatment of transferred patient because their therapy may be complex to manage
		Chronic patient with low expectation of improvement	Boredom especially in patients who arrive in very chronic conditions
		Non collaborative patient	A child never stands still during sampling blood
Caregiver-Parents interaction	Caregiver - > Parents	Language understanding	Not knowing the patient's language
		Explanation and perception of disease	A child with a rare disease may not be as difficult to clinically manage as a child with acquired brain damage, but it is not easy to make the concept understandable to parents
	Parents - > Caregiver	Requests during medical procedure	During the blood sampling, I heard the parent say: - I recommend only one hole!
		Demanding parents	Managing the parent, his needs and his difficulties, sometimes causes some stress

due to too rigid materials that limit movement. Finally, sanification procedures were also described as cause of mental effort. The nurse described the procedure of hand sanification, which has also some implication on uniform (that must be comfortable enough to roll up the sleeves) and the duty of not wearing rings and bracelets. Furthermore, all the caregivers underlined the need of dressing different clothes before entering the patient's room, depending on the bacterial/viral contamination of each patient and undressing at the end of the visit/procedure/rehabilitation. This was described as a cause of mental effort.

Caregiver-Patient Interaction. Secondly, the FG focused on the interaction between caregiver (clinician, physical therapist or nurse) and patient. This topic was sub-divided in two macro areas: "care process" and "clinical condition of patient".

"Care process" refers to activities and tasks requiring physical effort to healthcare operators. Researchers proposed to assess the interaction between the caregiver and the patient's bed, but it emerged the needs of assessing the interaction with the patient him/herself. The suggestion to use RFID technology was highlighted by the discussion among FG participants. Maintaining awkward postures, handling low loads at high frequency were identified as the most physically demanding activities. Hygiene, medications and containment are other activities identified as causes of physical stress.

In particular, the nurse and physical therapists involved in the focus group agreed that the lumbar and back region was the most physically stressed; for physical therapists interacting with children, the knees are also stressed because rehabilitation activities are usually performed on the floor. The overall physical strain rating scale confirmed the location of major effort (Fig. 3). Concerning the intensity of the physical strain, the physical therapists rated with –1 and –6 the knees and both with –3 the back region. The nurse indicated also the shoulders and wrists but did not rate the intensity of the strain. Finally, the clinician said they usually do not suffer from physical effort. This topic, as shown in Fig. 3, is not so relevant for the clinicians who do not experience much physical effort with patients but are more mentally/ emotionally stressed by their health condition. "Clinical condition" refers to the health condition and behavior of the patient involved in the therapy. A chronic pathology makes the clinical process more difficult to manage and requires a lot of mental effort from doctors and nurses who have to control the situation avoiding worsening of patient's condition. On the other side, a patient who does not improve or who is not cooperative can become a source of stress for the physical therapist.

Caregiver-Parents Interaction. The last theme touched during the focus group is related to the interaction between caregiver and the patient's family.

The first point debated is the caregiver's problem in relating to the parents. One problem that raised concerns is the correct explanation of the disease to the family members. Indeed, being emotionally involved, caregivers declared that they tend to perceive some diseases as more severe than they are. This problem is common to figures such as clinicians and nurses causing them cognitive stress. This situation is aggravated by the linguistic difficulty in communicating with relatives. In addition to the previously mentioned problems, there are some relational and communication problems of the relatives towards the caregiver. One of the causes of cognitive stress is due to demanding

parents who continuously ask for clarifications/explanations. On the other hand, there are parents who are very demanding during some medical procedures such as blood sampling.

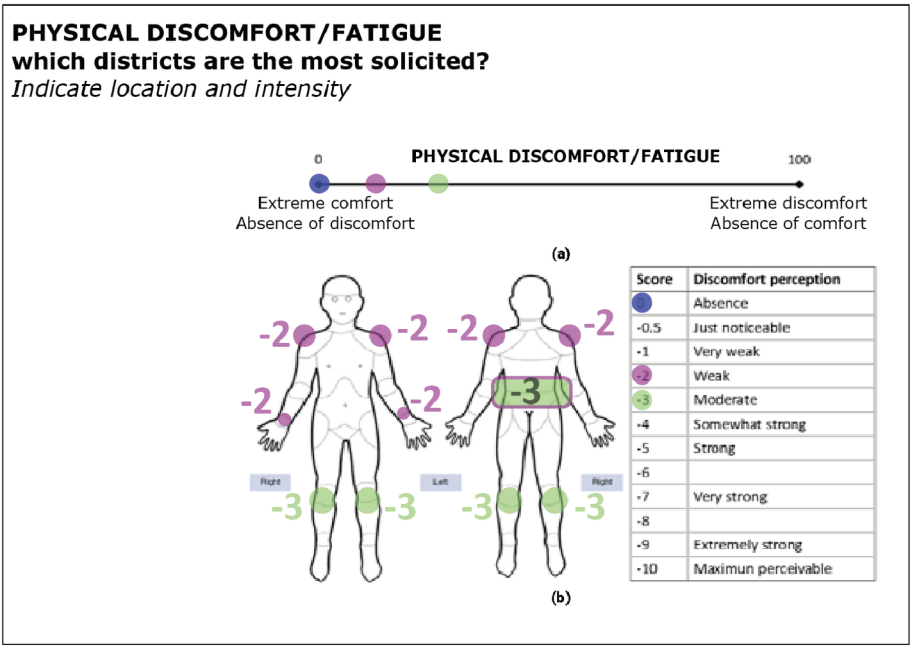

Fig. 3. The body map to investigate the level of physical discomfort/fatigue. The participant has to indicate in the image the zone afflicted by the disease, specifying the intensity (on a scale from 0 to –10). The colors of the dots represent the caregiver category: purple = nurse, green = physical therapists, and blue = doctor.

3.3 Definition of Technical Requirements

The topics emerged during the FG were used- when possible - to define the system requirements, the first outcome of the codesign activity.

Considering that all the caregivers declared to suffer from both mental and physical effort, the first requirement was to have a set of sensors to monitor physical strain and another one to measure physiological data related to mental wellbeing.

Considering the theme related to the uniform and to the environmental discomfort, the second requirement was to have a breathable garment having the following features:

– It must support the monitoring of the caring effort for the operators though an embedded RFID system (passive on patient, active on caregivers) which evaluates the average time-per-patient;
– It must support the assessment of the biomechanical load of the healthcare worker both daily and related to each single patient (triggered by RFID) using a set of inertial

units in the wearable garment and corresponding to simplified biomechanical model (e.g. by MAPO index or similar);
– It has to integrate the assessment of the operator's stress level through the recording of parameters from the Autonomous Nervous System like Heart Rate Variability (HRV) and respiratory rate. This implies the adoption of 1 ECG lead by means of at least two textile electrodes embedded in the smart garment. Measuring the HRV will provide an index for mental wellbeing assessment. Time-domain parameters will be used as main indicators of the effort/arousal status for short term analysis and feedback, while a more complete data processing adding also frequency domain parameters could be done on the off-line downloaded data.

The sensorized garment can be integrated by a wearable bracelet for clinicians and physical therapists. Figure 4 shows possible configurations for each healthcare workers.

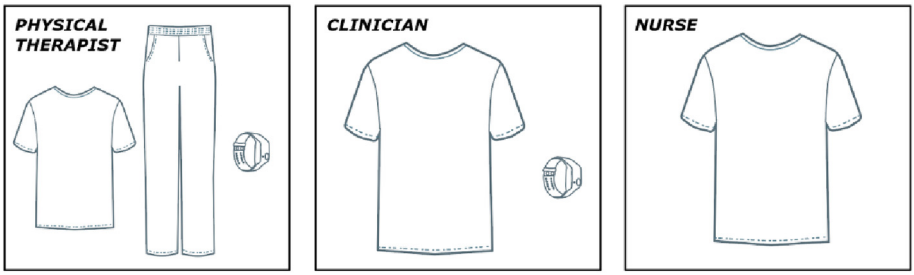

Fig. 4. Possible configurations of the monitoring system divided by healthcare operator. Each configuration is proposed taking into consideration the needs expressed by the focus group participants. The common element among these three set-ups is the sensorized t-shirt.

4 Discussion

In this work, we present the definition of the requirements phase through a codesign methodology to develop a smart solution for monitoring the physical, cognitive and organizational effort of caregivers in a rehabilitation hospital setting. In addition, the user's preferences about a data presentation interface (online for the wearable or linked app, or webapp for a remote PC connection) that can display collected data and provide some services. Codesign method (that we exploited in the form of the FG) allowed to highlight three main categories of working conditions: organization, relationship with the patient, and relationship with the patient's relatives.

Among the participants in the FG, the major interest was dedicated to the assessment of cognitive stress, which turn out to be the predominant aspect for the working environment and conditions. The stress level can be obtained through the acquisition of HRV. Another solution could have been the measurement of the electrodermal activity (EDA), but, in our case, this latter would be not applicable because of the positioning of the sensors onto the fingers. Environmental conditions certainly have impact on the

work experience: FG participants identify environmental temperature as an important aspect to be added in the sensors set.

Starting from the expressed needs, the main system configuration should include sensors to monitor the cognitive stress more than the physical effort. The physical component of the work analysis is important for the nurse about the upper limbs and for the physical therapists focusing on both upper and lower limbs. To this purpose, the system could also embed some EMG sensors for the main muscles of the corresponding anatomical districts of the body (biceps and triceps for the upper limbs, rectus femuri and anterior tibialis together with gastrocnemii and soleus for the lower limbs - the gluteus maximus could be interesting but its measurement was considered too obtrusive); this datum would integrate the kinematic measures so improving the overall reliability, but it is would be worth of consideration during the development phase that it would imply a very complex hardware configuration thus affecting the ecological monitoring required by the application. For this reason, at first decision in requirement definition, this option was left only for future improvements.

About data displaying, the wearable system is not expected to have a dedicated UI. Data logging is the preferred option so that data download at the end of the working time and offline data processing and visualization is to be done.

During the FG also the issue related to how this system will be provided and the effort required to its introduction and functioning into the care practice. The healthcare workers showed some hesitation towards the adoption of the device, therefore it was agreed that joining this project will be voluntary. Another aspect that the users underlined was about the effort needed: it is mandatory to have a very unobtrusive system that requires low effort and works autonomously without requiring further actions/inputs.

Finally, data protection and privacy issues were discussed at the end of the FG: all users agreed in the anonymous data sharing to monitor the working conditions at general level and to highlight possible problems. The possibility to have a personal dashboard was considered interesting.

5 Conclusions

This paper discusses the first results from a Codesign activity to develop a wearable system for monitoring health and wellbeing condition of healthcare worker in a rehabilitation hospital setting. From a methodological point of view, we have reached a further demonstration of the validity of the participatory design approach to define reliable and precise product-system specifications. The next steps are the development of two further FGs, one targeted to the UX/UI for the visualization mode and related applications, and the second focused on the development of possible corporate welfare services.

The current activity has two limitations: the first one is the low number of participants and the second is the specificity of the hospital. In fact, the analyzed context is a pediatric rehabilitation hospital, so attention for results generalization has to be considered.

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